SPECIFICATION

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[SYSTEMS AND METHODS FOR ESTIMATING SPEED AND PITCH SENSOR ERRORS]

Background of Invention

[0001] FIELD OF THE INVENTION. The present invention relates generally to vehicle navigation systems, and more particularly, to systems and methods for estimating the bias and scale factor in a speed sensor and pitch sensor using a modified adaptive filter.

[0002] BACKGROUND OF THE INVENTION. Many navigation systems rely on satellite-based global positioning ("GPS") devices, including at least a number of which have been applied in automobile navigation systems. Conventional methods for correcting GPS positions are referred to as differential GPS ("DGPS").

[0003] Integrated navigation systems ("INS") are employed within vehicles in order to provide vehicle position and velocity information with respect to a specified reference frame. A typical INS determines estimates for the position and velocity of a vehicle based on a collection of data taken from inertial sensors such as acceleration and rate sensors mounted in the vehicle, as well as sensors based outside the vehicle, such as a GPS. Typically, the INS will use this sensed information, along with a model of vehicle motion behavior to form a set of navigation equations, in order to estimate vehicle position information and derivations therefrom. Conventional INS may be used in "turn-by-turn navigation" systems, "in vehicle dynamics" systems, and within proposed vehicle enhancements such as "adaptive cruise control." A key element and/or function of the INS is the estimation of sensor errors used in the navigation equations. All sensors used by the INS have a scale factor that relates the sensor output to the sensed attribute, and a bias error; i.e., the sensor has a nonzero output

even when the sensed attribute is zero. If the bias error or scale factor estimates are calculated incorrectly, the calculated vehicle position, heading, and/or speed will be in error, and the reliability of the INS will be undesirably reduced. This sensor error estimation is especially important in situations where data from the GPS may become unavailable such as under bridges or within tunnels.

[0004] Efforts have been made to reduce the impact of the scale factor and bias error estimation through the use of high quality inertial measurement equipment. However, the relatively high cost of such equipment is prohibitive for automotive applications. Hence, sensor error estimation is critical in conventional systems utilizing lower quality sensors. Conventional sensor error estimation is typically performed by developing sensor error models, and then implementing the model parameter estimation as augmented equations in the overall set of navigation equations, usually in a "Kalman" filter. The Kalman filter approach has desirable stability properties, but is somewhat limited, as it provides only statistical representations of errors, and requires the implementation to be added to the overall navigation equations. Other attempts at estimating these types of sensor errors have been made using neural networks. While neural networks have the advantage of learning in the presence of noise, they often require a relatively large number of learning examples, referred to as a training set, which are needed for the training phase. The required "training" process is relatively complicated, time consuming, and computationally intensive, and is therefore not suited to be carried out "on-line" or during the normal use of a vehicle.

[0005] What is needed are systems and methods for estimating bias and scale factor in speed and pitch sensors within an integrated navigation system.

Summary of Invention

[0006] In one embodiment, the present invention provides systems and methods for estimating the bias and scale factor in a speed and pitch sensor using a modified adaptive filter. The adaptive filter estimates errors in a vehicle's speed and pitch angle during the availability of DGPS, and can use these estimated values to aid the INS during DGPS outages or unsuitable DGPS solutions. The systems and methods of the present invention may be applied successfully to navigation problems, such as in automotive applications.

[0007] In a preferred embodiment, the present invention provides a system for estimating an error in a first sensor. The system includes a first sensor that generates a first signal, a second sensor that generates a second signal, a module communicatively coupled to the first and second sensors, and an adaptive filter communicatively coupled to the module. The module generates values based on signals received from the first and second sensors, and combines those values to generate a third value. The adaptive filter receives the first value and the third value, and estimates the error in the first sensor based upon those values. The sensors include speed, pitch, differential global positioning system, and an integrated navigation system. The errors include scale and bias errors.

[0008] In a preferred embodiment, the present invention provides a method for performing a position calculation using an estimate of an error in a sensor. The method comprises obtaining a plurality of signals from a sensor during a predetermined period of time, estimating the error using a filter that receives signals, storing the estimate of the error in a module communicatively coupled to the filter, and utilizing the estimate of the error to perform a position calculation during a period of time.

Brief Description of Drawings

[0009] Figure 1 is a functional block diagram illustrating one embodiment of a linear neuron design used by the system for estimating sensor errors which is made in accordance with the teachings of the preferred embodiment of the present invention; and

[0010] Figure 2 is a functional block diagram illustrating one embodiment of a method for estimating the scale factor and the bias factor of a speed sensor and a pitch sensor of an INS.

Detailed Description

[0011]

As discussed above, an integrated navigation system (INS) may be utilized within a vehicle, such as an automobile, to provide vehicle position information and vehicle velocity information with respect to a predetermined frame of reference. Typically, an INS estimates the position and velocity of a vehicle based on a plurality of data

received from inertial sensors, such as acceleration sensors and rate sensors, disposed within the vehicle, as well as sensors located outside of the vehicle, such as a differential global positioning system (DGPS). Typically, the INS utilizes this sensor information, along with a model of vehicle motion behavior, to form a plurality of navigation equations utilized to estimate vehicle position and derivatives thereof. A key element in and/or function of the INS is the estimation of sensor errors taken into account by the navigation equations.

[0012] In general, the present invention provides systems and methods for estimating the scale factor and the bias factor of a speed sensor and a pitch sensor of an INS. A scale factor relates the output of a given sensor to the sensed attribute. A bias factor relates to the fact that a given sensor may have a non-zero output even when the sensed attribute is zero. These systems and methods utilize a modified adaptive filter. The filter learns adaptively, in a random manner, to estimate errors in vehicle speed and pitch angle calculations. The aiding measurement utilized by these systems and methods is DGPS travel distance. The filter is operable for adaptively estimating speed measurement and pitch measurement error source values during the availability of DGPS service and DGPS travel distance measurements. These estimates may then be utilized by the INS during DGPS service outages or in the event of unsuitable DGPS solutions. In other words, the filter is operable for generating a scale factor/bias factor model, during vehicle operation and during the availability of DGPS service and DGPS travel distance measurements, that may be utilized by the INS and the associated speed sensor(s) and pitch sensor(s), during the unavailability of DGPS service and DGPS travel distance measurements. Thus, the systems and methods of the present invention allow an INS to function properly at virtually all times, and provide a means for solving the navigation problem. These systems and methods may be applied to any navigation application, such as an automotive navigation application, that utilizes speed sensors, pitch sensors, or both.

[0013] In one embodiment, a system for estimating the scale factor and the bias factor of a speed sensor and a pitch sensor of an INS includes all or a portion of the INS communicatively coupled to an adaptive filter. As is well known by those of ordinary skill in the art, the INS may include a processor and one or more memory devices. The present invention is embodied in a microprocessor based system that utilizes

arithmetic units to control processes according to software programs. Typically, the programs are stored in read-only memory, random access memory, or the like. The present invention is particularly well adapted for use with any conventional microprocessor based system. The software program may be readily coded using any conventional computer language. The process of writing software code is a mere mechanical step for one skilled in the art. The INS is also preferably in communication with a plurality of sensors and systems that transmit signals which are received by the INS. These sensors and systems may include, for example, a speed sensor, a pitch sensor, and a DGPS.

[0014] The speed sensor and the pitch sensor in communication with the INS of the vehicle have two primary sources of error: a scale factor and a bias factor. In operation, if the scale factor and the bias factor are not measured, calculated, or estimated correctly, the reliability of the INS may be reduced and the apparent position of the vehicle may be in error. This is especially true in INS's utilizing lower-quality speed sensors and pitch sensors. As discussed above, the DGPS service may periodically become unavailable, such as when the vehicle passes under a bridge or other structure or, for example, enters a tunnel. At such times, direct measurements of the scale factor and the bias factor are unavailable, and estimates must be relied upon.

[0015] The x-y INS travel distance (D_{ins}) is represented by the following equation:

[0016]

$$D_{ins_k} = D_{ins_{k-1}} + v_{k-1} \cos\theta_{k-1} dt_l. \qquad (1)$$

[0017] The x-y DGPS travel distance (D_{dgps}) is represented by the following equation:

[0018]

$$D_{dgps_k} = D_{dgps_{k-1}} + \sqrt{(x_k - x_{k-1})^2 + (y_k - y_{k-1})^2}. \qquad (2)$$

[0019] The DGPS travel distance is utilized as the aiding measurement by the INS for estimating the scale factor and the bias factor of the speed sensor and the pitch sensor during DGPS service outages or in the event of unsuitable DGPS solutions because the DGPS travel distance is independent of the heading angle of the vehicle.

[0020] The pitch angle (θ) is represented by the following equation:

[0021]

$$\theta_k = a\tan\left(-(h_k - h_{k-1})\Big/\sqrt{(x_k - x_{k-1})^2 + (y_k - y_{k-1})^2}\right). \qquad (3)$$

[0022] Thus,

[0023]

$$\theta_k = a\tan\left(-v_z\Big/\sqrt{v_x^{\,2} + v_y^{\,2}}\right). \qquad (4)$$

[0024] The sensor area model is represented by the following equation:

[0025]

$$D_{E_k} = D_{E_m} + \delta K_{vc_{mk}} S_{v_{m,k}} dt_i + B_{vc_{mk1}} T + S_{n_{0,k}} dt_i, \qquad (5)$$

[0026] where D_E is the error in the open loop x-y INS travel distance, δK_V s the scale factor of a given speed sensor, B B_V is the bias factor of the speed sensor, and S_V is the sum of the velocities-pitch angle product between two epochs.

[0027] Referring to Fig. 1, in one embodiment, the adaptive filter design 10 of the present invention simulates equation (5) and utilizes a modified adaptive filter 12. As discussed above, the filter 12 learns adaptively, in a random manner, to estimate errors in vehicle speed and pitch angle calculations. The desired target is the open loop x-y INS travel distance (D_{ins}) 14 minus the x-y DGPS travel distance (D_{dgps}) 16, which represents the error in the open loop x-y INS travel distance (D_E) 18. The weights are the estimated scale factor (δ K) 20 and the estimated bias factor (B) 22, and the inputs are the pitch rate sum (S) 24 and time 26. A bias input value of one (1) preferred if T is the time calculated from zero (0). This is necessary to estimate the initial error in the open loop x-y INS travel distance. The estimated scale factor and bias factor are fed back into the INS to predict the error in the INS position for the next DGPS period. The adaptive filter design 10 of the present invention dynamically integrates INS and DGPS utilizing a linear neuron, thereby automatically and effectively eliminating errors in the vehicle speed measurements and pitch measurements

[0028] Referring to Fig. 2, in one embodiment, a method 30 for estimating the scale factor and the bias factor of a speed sensor and a pitch sensor of an INS comprises,

during the availability of DGPS service 32, obtaining a plurality of DGPS travel distance measurements (Block 34). Utilizing these DGPS travel distance measurements, a modified adaptive filter is utilized to adaptively estimate the scale factor and the bias factor for the speed sensor and the pitch sensor of the INS (Block 36). These scale factors and bias factors are then stored within the INS (Block 38). During DGPS service outages or in the event of unsuitable DGPS solutions 40, the adaptively estimated scale factor and bias factor are retrieved by the speed sensor and the pitch sensor (Block 42) and are used by the INS to perform position calculations (Block 44).

[0029] Although the present invention has been described with reference to preferred embodiments and examples thereof, other embodiments may achieve the same results. Variations in and modifications to the present invention will be apparent to those of ordinary skill in the art and the following claims are intended to cover all such equivalent embodiments.